

Citation:

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Physics. — “Measurements on the capillarity of liquid hydrogen”.

By H. KAMERLINGH ONNES and H. A. KUYPERS. (Communication N^o. 142*d* from the physical laboratory at Leyden).

(Communicated in the meeting of June 27, 1914).

For the determination of the capillary constant of liquid hydrogen in contact with its saturated vapour the method of capillary rise was used. The apparatus are in the main arranged in the manner as used for other liquid gases in Comm. N^o. 18. On plate I A of Comm.

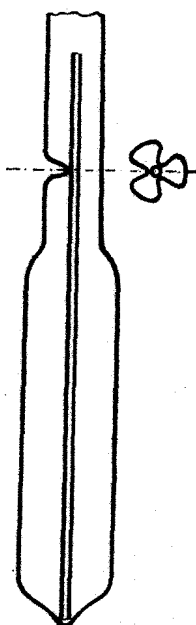


Fig. 1.

N^o. 107*a* may be seen that part of the apparatus which serves to condense the gas in the wide experimental tube (fig. 1), inside which is the capillary; for this purpose the tube of fig. 1 is sealed in at g_2 .

The radii of the sections of the tubes were found by calibration with mercury as follows:

radius of the capillary	inside $r = 0.3316$ cm
” ” ” ”	outside $r_1 = 0.0801$ cm
” ” „ surrounding tube	inside $R = 0.554$ cm

Measurement of the capillary rise. The reading of the ascension gave some trouble as it had to be made through a number of glass vessels and baths. The rise was measured with a cathetometer; to test the accuracy of the readings they were taken one time on a millimetrescale which had been etched on the capillary and another time directly on the scale of the cathetometer. When it was found, that there was no difference between the heights obtained in the two ways, they were afterwards only measured by means of the scale of the cathetometer, because, when the cryostat was filled with the different liquid gases, the divisions on the capillary were difficult to distinguish owing to the rising gas-bubbles in the liquids.

Temperature. The temperature was deduced from the pressure of the vapour in the hydrogen-bath using the vapour-pressure curve (H. KAMERLINGH ONNES and W. H. KEESOM, Comm. N^o. 137*d*, table on page 41).

Observations. The heights measured and the corresponding temperatures of the hydrogen are contained in the following table.

Repeated measurements show, that the accuracy of the reading of the rise may be estimated at 0.002.

TABLE I.

Temperature in KELVIN-degrees	Rise in cms.
20.40	1.616
18.70	1.794
17.99	1.869
16.16	2.064
14.78	2.209

The observed heights (h) have to be corrected for the curvature of the surfaces by means of the following formulae: (1) the correction for the meniscus in the narrow tube is $\frac{r}{3}$ ¹⁾. (2) the correction for the ring-shaped meniscus is (according to VERSCHAFFELT Comm. N°. 18).

$$h' = \left(h + \frac{r}{3} \right) \frac{\frac{2d}{(R-r_1)^2}}{1 - \frac{2d}{r(R-r_1)^2}}$$

For this correction the height of the ring-shaped meniscus, as the minor axis of the elliptical section with a meridian plane, is required to be known. With the illumination used this height could not be measured accurately. Afterwards for further correction we hope to be able to determine its value by special measurements: in the mean time the section was assumed to be circular with sufficient approximation. The corrected values are given in column 6 of table II.

When the capillary rise is plotted as a function of the temperature — fig. 2 —, a straight line is obtained. The constants determined from this line give the formula

$$H = - 0.1124 T + 40.44.$$

This formula gives $H = 0$ for $T_{H=0 \text{ extrap.}} = 35.98 \text{ K}$.

Assuming the critical temperature to be $T_k = 31.11 \text{ K}$ (mean of

¹⁾ LAPLACE, Méc. Cél. Tome X, Supp. § 5, Paris 1805.

id. , Oeuvres Tome IV, p. 415, Paris 1845.

ALLAN FERGUSON, Phil. Mag., p. 128, (6) 28, 1914.

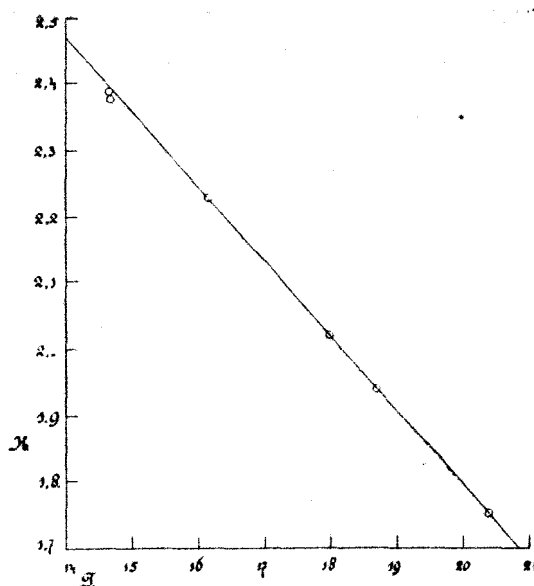


Fig. 2.

DEWAR, OLSZEWSKI and BULLE¹⁾) it is seen, that the formula, as was to be expected, does not hold up to the critical temperature and that the curve which gives the dependence of H on the temperature has its concave side towards the temperature-axis. The difference $T_{H=0 \text{ extrap.}} - T_k$ for hydrogen amounts to

$$T_{H=0 \text{ extrap.}} - T_k = 3.87.$$

If $T_{H=0 \text{ extrap.}} - T_k$ is divided by the critical temperature the positive value $\frac{3.87}{3.21} = 0.125$ is obtained. For methyl-chloride²⁾) and ethylether³⁾) similar values are obtained⁴⁾).

Surface-tension. From the capillary rise the surface-tension ψ_r is found by means of the following formula:

$$H = \frac{2\psi_r}{(\rho_{\text{liq.}} - \rho_{\text{vap.}})g} \left(\frac{1}{r} - \frac{1}{R-r_1} \right).$$

The densities for liquid hydrogen are taken from the observations by H. KAMERLINGH ONNES and C. A. CROMMELIN (Comm. No. 137a).

1) F. BULLE. Physik. Zeitschr. p. 860, XIV, 1913.

2) According to measurements by J. VERSCHAFFELT; comp. A. v. ELDIK, Comm. N^o. 39, p. 14.

3) E. C. DE VRIES, Comm. N^o. 6.

4) The corresponding figures (deduced, however, from not-corresponding temperature ranges) are 0.038 and 0.017 respectively.

For the calculation of the vapour-densities use is made of the second virial coefficient, as deduced from the measurements by H. KAMERLINGH ONNES and W. J. DE HAAS (Comm. No. 127c).

TABLE II.

Temp.	h	Correction for the meniscus		H	$Q_{\text{liq.}}$	$Q_{\text{vap.}}$	$Q_{\text{liq.}} - Q_{\text{vap.}}$	ψ_{σ} observ. dyn./cm.	$O-C$
		inside	outside						
20.40° K	1.616	0.011	0.122	1.749	0.0708	0.0013	0.0695	2.126	-0.011
20.39 ⁵	1.617	11	122	1.750	708	13	695	2.127	-0.011
20.39	1.619 ⁵	11	122	1.752 ⁵	708	13	695	2.130	-0.009
18.70	1.794	11	136	1.941	726	08	718	2.438	-0.005
17.99	1.869	11	141	2.021	733 ⁵	05	728 ⁵	2.575	+0.004
16.16	2.064	11	156	2.231	751	03	748	2.919	+0.019
14.68 ⁵	2.199	11	166	2.376	764	02	762	3.167	+0.004
14.66	2.209	11	167	2.387	764	02	762	3.182	+0.015

With these data the values of ψ_{σ} in table II are calculated. Under $O-C$ are given the differences between $\psi_{\sigma \text{ obs.}}$ and values of ψ_{σ} calculated from VAN DER WAAALS' formula

$$\psi_{\sigma} = A(1-t)^B$$

where

$$A = 5.792$$

$$B = 0.9885$$

From the value found for B it appears, that ψ_c as a function of T is nearly a straight line.

The constant in EÖRVÖS' formula for hydrogen deviates considerably from the value 2.12, found by RAMSAY and SHIELDS ¹⁾ as the average for a number of normal substances. In Table III the values of k_{EG} for a few of these substances, together with those for some liquid gases, are collected. As observed by KAMERLINGH ONNES and KEESOM (note 381 Suppl. No. 23), normal substances form a series in this respect, on the whole progressing with the critical temperature (although with deviations which may be ascribed to particularities in the law of molecular attraction, e.g. with oxygen).

TABLE III.

Ethylether ²⁾	2.1716
Benzene ²⁾	2.1043
Argon ³⁾	2.020
Nitrogen ³⁾	2.002
Carb.monoxide ³⁾	1.996
Oxygen ³⁾	1.917
Hydrogen	1.464

A calculation of the constant k' in EINSTEIN'S formula ⁴⁾.

$$\left[\left(\psi_c - T \frac{d\psi_c}{dT} \right) v_{\text{liq. } M}^3 = k' (\lambda_{Mp=1} - RT) \right]_{T=20.33}$$

for hydrogen gives

$$7.34 \times 10^{-9}$$

The fact, that hydrogen appears to have a considerably higher value of k' than that calculated by EINSTEIN for benzene, might, in view of the theory underlying the formula, indicate, that the radius of molecular action is larger for hydrogen molecules than for substances like benzene.

¹⁾ J. chem. Soc. 63 (1893); ZS. f. physik. Chem. 12 (1893).

²⁾ RAMSAY and SHIELDS ZS. f. physik. Chem. 12 (1893), 15 (1894).

³⁾ BALY and DONNAN, Journ. chem. soc. 81 (1902).

⁴⁾ A. EINSTEIN, Ann. d. Phys. 4. 34, 1911.